NBER WORKING PAPER SERIES

UNIVERSITY INVENTION, ENTREPRENEURSHIP, AND START-UPS

Celestine Chukumba
Richard Jensen

Working Paper 11475
http://www.nber.org/papers/w11475

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2005

We thank participants in the NBER Summer Institute Pre-Conference and the NBER Conference on Academic Science and Entrepreneurship: Dual Engines of Growth?, the Notre Dame Economics and Econometrics Brownbag, and the Fourth REER Conference, B.J. Lee, Josh Lerner, Nelson Mark, Larry Marsh, Suzanne Scotchmer, Scott Shane, Jim Sullivan, Jerry Thursby, Chris Waller, and Arvids Ziedonis for helpful comments and discussions. We also thank the TTOs, university administrators, and licensing consultants whose willingness to talk to us about their licensing experience was helpful in formulating our theoretical model. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 11475
July 2005
JEL No. L31, O31, O32

ABSTRACT

This paper develops a game-theoretic model that predicts when a university invention is commercialized in a start-up firm rather than an established firm. The model predicts that university inventions are more likely to occur in start-ups when the technology transfer officer's (TTO's) search cost is high, the cost of development or commercialization is lower for a start-up, or the inventor's effort cost in development is lower in a start-up. We test the theory using data from the Association of University Technology Managers, the National Research Council, and the National Venture Capital Association. Licensing is more likely in general, and especially so in start-ups, by universities in states with larger levels of venture capital. TTO size has no effect on start-ups, but does increase licences. Conversely, universities that earn greater licensing royalties have fewer start-ups but more licenses. The number of start-ups is decreasing in the interest rate, increasing in the S&P 500, and unaffected by the levels of industrial research funding and the presence of a medical school. All of these results are consistent with the predictions of our theory.

Celestine Chukumba
Department of Economics and Econometrics
434 Flanner Hall
University of Notre Dame
Notre Dame, IN 46556
celestine.o.chukumba.1@nd.edu

Richard Jensen
Department of Economics and Econometrics
434 Flanner Hall
University of Notre Dame
Notre Dame, IN 46556
rjensen1@nd.edu

1 Introduction

The Bayh-Dole Act of 1980 led to an explosion in the growth of technology transfer offices in U.S. universities, as well as a substantial increase in the commercialization of university inventions and resulting revenue. Gross license royalties paid to universities in the Association of University Technology Managers (AUTM) annual surveys for 1993 through 2002 increased by a remarkable 284%, from roughly $238 million to $915 million. The commercialization of university inventions was dominated by established firms during this period. On average, each surveyed university annually licensed 25 inventions to established firms, but only 3 inventions to start-up firms. This ratio has been reasonably constant during this period as well. AUTM data show that the number of licenses executed with established firms grew by 90%, while the number of licenses with start-ups grew by 105%. Given the embryonic nature of most university inventions, it is somewhat surprising that there has not more commercialization via start-ups. This paper develops and empirically tests a theory that attempts to explain this by examining reasons for the commercialization of university inventions through start-up firms as opposed to established firms.

Technology transfer officers (TTOs) are responsible for making good-faith efforts to commercialize university inventions. This process begins when a faculty member discloses a potential invention to the TTO, who then tries to find a partner for commercialization. Typically, if the TTO is unable to find an established firm willing to acquire a license for this new technology, then it shelves the invention. That is, the TTO returns it to the inventor, who may then seek venture capitalists or angel investors to help fund a start-up firm in order to attempt to commercialize the invention. In fact, the TTO may even return it to the inventor immediately, without even trying to find an established firm to license it. In this event, the TTO may assist the inventor in searching for an investor to fund a start-up, but typically TTOs focus their efforts on licensing inventions to established firms.

We formalize this by developing a game-theoretic model of university licensing. The model provides two key implications regarding commercialization by start-up firms rather than established firms. First, if the TTO's utility cost of searching is the same for both types of firms, then start-ups occur in equilibrium only if a start-up firm earns greater expected profit, gross of any license payments, than an established firm, so that the TTO can earn greater net utility from licensing to a start-up under the optimal contract. This occurs if a start-up firm has a cost advantage in additional development or commercialization. For example, venture capitalists routinely deal with new products and processes, so they may well have better access to and/or information about the expertise needed to develop and commercialize embryonic inventions, which would provide a start-up firm with a cost advantage. Similarly, inventor-founded start-ups may well have cost advantages due to the inventor's superior knowledge of the technology, which can limit transactional and informational problems (Shane 2002). Also, if there is a lower opportunity cost of development effort for either the inventor or firm in a start-up, then either may provide greater effort in the development stage, which results in a higher probability of success and greater expected profit for the start-up. The second main implication is that licensing to a start-up can occur, even if expected profit is the same for both types of firms, simply because the TTO's opportunity cost of searching for an established firm as a licensee is greater. This occurs, for example, if the TTO has a large pool of higher-quality disclosures available, so less attractive ones are immediately shelved.

We summarize the empirical implications of the theory in terms of characteristics of the inventor, the TTO, and the invention, and financial market conditions. Our empirical analysis uses data from the AUTM surveys for 1993-2002, the 1993 National Research Council's Survey of Ph.D. Granting Institutions, and the National Venture Capital Association Yearbook 2004. We estimate models for the number of licenses to start-ups and the number of licenses (and options) to established firms per university in each year. In general, like Di Gregoriao and Shane (2003), our results provide evidence that universities with higher quality faculty are more likely to license their inventions to either start-ups or established firms. More importantly, we find that the quality of the university's engineering faculty, rather than that of the science faculty or the entire faculty, is the most significant influence on the number of licenses.

We find support that the Bayh-Dole Act has been effective in the sense that TTOs have significantly influenced university licensing. Our result show that both the age of the TTO and the number of disclosures made to the TTO had positive and significant impacts on licensing to either start-ups or established firms. Gross license royalties also had a positive and significant impact on licensing to established firms, but not start-ups. Somewhat surprisingly, the size of the TTO did not have a significant effect on licensing to either type of firm.

Finally, our results also provide evidence that financial market conditions matter for licensing via start-ups. We finds that both the rate of return to venture capital and the interest rate have negative and significant effects on the number of university start-ups, but general market conditions, as measured by the S&P 500, have a positive and significant effect on start-ups. Thus, our analysis indicates that one answer to the question of why there are not more university start-ups is that university inventions are not just embryonic, but very embryonic. If an established firm is unwilling to take a license, then it is very difficult to find the funding for a start-up because even the venture capitalists who specialize in start-ups come to university inventions only as a last resort, when the returns to venture capital elsewhere are very low.

2 Literature Review

Our results contribute to the growing theoretical literature on the licensing of university inventions, which has predominantly focused on the effects of the Bayh-Dole Act, and the behavior of inventors and TTOs: Jensen and Thursby (2001), Lach and Shankerman (2002), Jensen, Thursby, and Thursby (2003), Thursby, Thursby, and Decheneaux (2004), Hoppe and Ozdenoren (2004), Macho-Stadler, Perez-Castrillo, and Veugelers (2004), and Hellmann (2005). One exception to this is Jensen and Thursby (2004), who study the effects of increased incentives to commercialize university research on the trade-off between applied and basic research, and the quality of education. What distinguishes our theoretical model is that all previous efforts have simply focused on the licensing or commercializing of the invention to some firm, rather than determining the conditions under which commercialization occurs through a start-up firm instead of an established firm.

Our results also contribute to the now extensive empirical literature on the commercialization of university research and start-ups. Much of the literature on university invention has abstracted from examining the role of university inventors and TTOs. Exceptions include Bercovitz *et al.* (2001) and Siegel *et al.* (1999), who take an organizational perspective, Thursby *et al.* (2001), Thursby and Thursby (2001), Jensen, Thursby, and Thursby (2003), and Thursby, Thursby, and Decheneaux (2004), who examine the role of TTOs in structuring license contracts, and Lach and Shankerman (2002), who study the number and value of inventor disclosures. Our work adds to this literature by analyzing the effect of both the quality of faculty and the historical success of the TTO on the choice between commercialization by established firms and start-ups.

Shane has examined factors influencing the performance of start-ups using data on inventions by MIT faculty. He shows that the formation of start-ups is fostered by both recognition of business opportunities by inventors (Shane 2000) and the presence of technological opportunities (Shane 2001). Shane and Stuart (2002) find that start-ups are more likely to succeed if the founders have relationships with venture capitalists. Di Gregoriao and Shane (2003) examine start-up formation across US universities, using AUTM data for the period 1994-1998, and find a positive relationship between start-up formation and faculty quality, as measured by the Gourman Report. Our empirical analysis, in part, updates and extends this study. The latter two studies include financial market factors in the form of availability of nearby sources of venture capital and IPOs, but do not examine more general measures of financial market activity, or measures of TTO experience. Finally, Shane (2002) compares MIT inventions licensed to established and start-up firms. He finds that licensing to inventor-founded start-ups is more likely when patents are ineffective at preventing information problems (such as moral hazard and adverse selection), because the inventor's superior knowledge of the technology precludes such problems in start-ups. However, he also finds that licenses to start-ups perform poorly compared to licenses to established firms, and concludes that licensing to start-ups on a second best solution for TTOs. This supports our assumption that TTOs generally prefer to license to established firms, and put far less effort into searching for start-up licensees. Similarly, Lowe and Ziedonis (2004) compare the outcomes of licenses to start-ups with those to established firms using data from the University of California and find that royalties from start-ups are higher, on average, but successful commercialization tends to occur only after acquisition by an established firm.

Other recent literature has examined start-up firm activity and licensing in general. Shane and Somaya (2004) use AUTM data and patent litigation data during 1991-2000 to examine the effects of patent litigation on university licensing efforts. Siegel *et al.* (1999) examine the relationship between licenses, TTO staff and legal expenditures in their analysis of university technology transfer. Feldman, Feller, Bercovitz and Burton (2002) find an increase in the use of cashed-in-equity in licensing agreements. Our analysis adds depth by examining factors related to commercialization of inventions in both established and start-up firms.

3 The Theoretical Model

The model is a reasonably straightforward compilation and extension of those in Jensen and Thursby (2001) and Jensen, Thursby, and Thursby

(2003). We model the problem as a multistage game with four players: the TTO, the inventor, an established firm, and an investor/entrepreneur. The game begins when the inventor discloses an invention to the TTO, who first decides either to shelve the invention (i.e., return it to the inventor), or to search for an established firm to which it offers a license contract. If a contract is offered, then the firm decides to accept or reject it. If the firm rejects the contract, then the TTO shelves the invention. If the firm accepts, it pays a fixed license fee, $M \geq 0$, and then a period of further development follows. This development results in an updated probability of success, which is common knowledge. The firm then decides whether to terminate the project, in which case the TTO shelves the invention, or to expend the additional resources necessary to attempt to commercialize it, in which case all interested parties learn if the invention is a success or failure. If it succeeds, the firm produces and pays total royalties of $R \geq 0$. If it fails, the game ends.

If an established firm acquires a license, then both the inventor and the licensee may expend further effort e_F and E_F in development in order to increase the probability of success. We assume these efforts are not contractible, but instead are chosen at the beginning of the development period (after the licensing agreement has been made) as the equilibrium outcomes $e_F^* \geq 0$ and $E_F^* \geq 0$ of a noncooperative subgame. These equilibrium efforts depend, in general, on the contract, $e_F^* = e_F^*(R_F, M_F)$ and $E_F^* = E_F^*(R_F, M_F)$.

As is well-known by now, university inventions are typically embryonic. Their commercial potential is uncertain, and the likelihood of their success is very small. We assume that the probability of success $p(e_F, E_F; Q, H)$ depends not only on the development efforts, but also on a measure of the quality of the inventor, Q, and a measure of the historical success of the TTO, H. We assume that p is increasing in the efforts, inventor quality, and past TTO success. It is evident that efforts and inventor quality are inputs in the "production" of a probability of success Including TTO success as an input as well implies that, *ceteris paribus*, an invention drawn at random from a faculty member at a university with a superior track record of success is more likely to be a success. We also assume that p is jointly concave in all its arguments, and that $p \in (0,1)$ for all $(e, E; Q, H)$. Finally, we assume that additional effort by the firm (in the form of more or better equipment, for example) should increase the marginal impact of inventor effort on the probability of success, $\frac{\partial^2 p}{\partial e \partial E} > 0$. That is, inventor and firm efforts are "complements" in development, in the sense that they complement each other in the production of a positive probability of success.

If additional development occurs and the invention is a success, then the firm chooses output to maximize its profit (net of any license fees). In general, because marginal production cost depends on the royalty rate, the firm's maximal output is decreasing in the royalty rate. Denote profit-maximizing output by $x(r)$ where $r \geq 0$ is the royalty rate per unit of output. Assume that $x(0) > 0$ and $x'(r) < 0$, and that total royalty revenue $R = rx(r)$ is strictly concave in r and has a unique maximum at a positive, finite value.[1] Because the "effort" provided by the firm can include materiel and personnel as well as cash grants, denote the cost of its effort by $C_F(E_F)$, which we assume is increasing at an increasing rate: $C_F(0) = 0$, $C'_F > 0$, and $C''_F > 0$. Finally, after development the firm must also pay a lump-sum cost to attempt to commercialize the invention, $K_F > 0$. Thus, if $\Pi(x(r))$ is the firm's maximized profit (gross of royalty payments) for any royalty rate r, then its expected payoff from accepting a contract (R_F, M_F) is

$$P_F(e_F, E_F) = p(e_F, E_F; Q, H)[\Pi(x(r_F)) - R_F] - M_F - C_F(E_F) - K_F, \quad (1)$$

where r_F is the royalty rate associated with the contract (R_F, M_F) (i.e., $R_F = r_F x(r_F)$).The firm accepts this contract and attempts to commercialize the invention (after development) only if $P_F(e_F, E_F) \geq 0$.

Conversely, suppose that the TTO shelves the invention, which can occur after the inventor discloses or after a potential licensee rejects a contract offer.[2] This commercialization of the invention occurs only if a venture capitalist or angel investor can be found to provide the effort required to create a new, start-up firm based on the invention, as well as to assist in additional development. TTOs typically expend little, if any, effort in this search process. The effort expended by the inventor in this case typically includes both search for investors and additional development, and so exceeds that when the licensee is an established firm. To economize on notation, we let e_S and E_S denote the total efforts expended by the inventor and the venture capitalist or angel investor.

Nevertheless, if a start-up is created, then it is still the role of the TTO to offer a license contract for the use of the invention. We assume it takes the same form, a combination of royalty and fixed fee, (R_S, M_S), where the

[1] These assumptions on royalty revenue hold for a broad class of new process innovations licensed to a single firm (including, but not limited to, the case of linear demand and constant marginal cost).

[2] The firm could agree to a contract, and then refuse to attempt to commercialize it after the development period if it is indifferent, $P_L(R_L, M_L) = 0$. In this case we assume the firm attempts the commercialization.

royalty rate is r_S and total royalties are $R_S = r_S x(r_S)$. Again we assume inventor and licensee efforts e_S and E_S are the equilibrium outcomes of a noncooperative subgame, and depend in general on the contract, $e_S^* = e_S^*(R_S, M_S)$ and $E_S^* = E_S^*(R_S, M_S)$. The start-up firm's cost of effort is $C_S(E_S)$, which we again assume satisfies $C_S(0) = 0$, $C_S' > 0$, and $C_S'' > 0$. If its lump-sum cost to attempt to commercialize the invention is $K_S > 0$, then its expected payoff from accepting the contract (R_S, M_S) is

$$P_S(e_S, E_S) = p(e_S, E_S; Q, H)[\Pi(x(r_S)) - R_S] - M_S - C_S(E_S) - K_S. \quad (2)$$

The venture capitalist assists in the creation of a start-up firm, which accepts this contract and attempts to commercialize the invention (after development), only if $P_S(e_S, E_S) \geq 0$.

Assume that, for each $j = F, S$, $\hat{E}_j$ is the maximum effort that firm j can devote to development. The continuity and strict concavity of each P_j guarantees that it is maximized at some $E_j \in [0, \hat{E}_j]$, and so there exists a firm j best-reply function $b_j(e_j)$. Moreover, $\frac{\partial P_j(e_j,0)}{\partial E_j} > 0 > \frac{\partial P_I(e_j,\hat{E}_j)}{\partial E_j}$ is sufficient to guarantee that P_j has an interior maximum at some $E_j \in (0, \hat{E}_j)$, in which case the first order necessary condition is:

$$\frac{\partial P_j}{\partial E_j} = \frac{\partial p}{\partial E_j}[\Pi(x(r_j)) - R_j] - C_j'(E_j) = 0. \quad (3)$$

It is worth noting that the firm expends effort on additional development, independently of the inventor, only if it can independently increase the probability of success.

The inventor's utility function takes the form $U_I(Y_I, \vartheta) - V_I(e)$, where Y_I is his income and ϑ is an indicator variable that equals 1 if a license is sold and 0 if not. That is, the inventor gains utility both from income and the prestige associated with the successful sale of a license (to any firm),[3] but suffers disutility from effort in further development, $V_I(e)$. Naturally we assume positive but nonincreasing marginal utility from income (so the inventor can be risk-neutral or risk-averse), positive marginal utility from sale of a license, and positive and increasing marginal disutility of effort: $\frac{\partial U_I}{\partial Y_I} > 0 \geq \frac{\partial^2 U_I}{\partial Y_I^2}$, $U_I(Y_I, 1) > U_I(Y_I, 0)$, $V_I' > 0$, and $V_I'' > 0$. Thus, if α_I is his share of license income, then for each $j = F, S$, his expected utility is

$$\begin{aligned} P_I(e_j, E_j) \quad &= \quad p(e_j, E_j; Q, H)U_I(\alpha_I(M_j + R_j), 1) + \\ &\quad\quad (1 - p(e_j, E_j; Q, H))U_I(\alpha_I M_j, 1) - V_I(e_j). \end{aligned} \quad (4)$$

[3] See Stephan (1996) for a survey of empirical support for the assumption that inventors also receive utility from nonpecuniary sources, such as seeing an invention licensesd or patent granted.

Now assume that $\hat{e}$ is the maximum effort that the inventor can devote to development. Then for each $j = F, S$, the continuity and strict concavity of P_I guarantees that it is maximized at some $e_j \in [0, \hat{e}]$, and so there exists an inventor best-reply function $b_I(E_j)$. Moreover, $\frac{\partial P_I(0,E_j)}{\partial e} > 0 > \frac{\partial P_I(\hat{e},E_j)}{\partial e}$ is sufficient to guarantee that P_I has an interior maximum at some $e_j \in (0, \hat{e})$, in which case the first order necessary condition is:

$$\frac{\partial P_I}{\partial e_j} = \frac{\partial p}{\partial e_j}[U_I(\alpha_I(M_j + R_j), 1) - U_I(\alpha_I M_j, 1)] - V_I'(e_j) = 0. \tag{5}$$

It is worth noting that, as in Jensen and Thursby (2001), the inventor expends effort on additional development only if the royalty rate is positive.[4]

Theorem 1 *Under the assumptions on the payoff functions and strategies, for each $j = F, S$ and given contract (R_j, M_j), there exists a Nash equilibrium $(e_j^*(R_j, M_j), E_j^*(R_j, M_j))$ for the development subgame between the firm and inventor. Furthermore, the equilibrium is:*
(i) No development, $e_j^* = E_j^* = 0$, if $\frac{\partial P_I(0,\hat{E}_j)}{\partial e} < 0$ and $\frac{\partial P_j(\hat{e},0)}{\partial E_j} < 0$;
(ii) Both inventor and firm j expend effort in development, $e_j^* > 0$ and $E_j^* > 0$, if $\frac{\partial P_j(0,0)}{\partial E_j} > 0$ and $\frac{\partial P_I(0,0)}{\partial e_j} > 0$; and
(iii) Unique and locally stable if and only if $b_I'(b_j'(e_j^*)) < 1$.

Proof. See the appendix. ■

Inventor and firm efforts, whenever they are interior, are strategic complements because they are complements in development: that is, $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $b_I'(E_j) > 0$ and $b_j'(e_j) > 0$. As long as their best-reply functions have the appropriate relative slopes, as depicted in figure 1, then there is a unique and locally stable equilibrium in which development occurs and each contributes to that development, $e_j^*(R_j, M_j) > 0$ and $E_j^*(R_j, M_j) > 0$ for each j.

The TTO's utility function is $U_T(Y_T, \vartheta) - V_{Tj}(Q, H)$, where Y_T is income. That is, the TTO also gains utility both from income and the prestige associated with the successful sale of a license, but suffers disutility from the search for a licensee. Again we assume positive but nonincreasing marginal utility from income, and positive marginal utility from sale of a license: $\frac{\partial U_T}{\partial Y_T} > 0 \geq \frac{\partial^2 U_T}{\partial Y_T^2}$ and $U_T(Y_T, 1) > U_T(Y_T, 0)$. We also assume that the utility cost of search depends on the type of licensee, inventor quality, and

[4] If $r_j = 0$, then $e_j = 0$ because he earns his share of the fixed fee, $\alpha_I M$, whether he expends any effort or not, and the marginal disutility of effort is positive, $V_I'(0) > 0$.

historical success of the TTO. In particular, the disutility of search is decreasing at a nonincreasing rate in inventor quality and past TTO success: $\frac{\partial V_{Tj}}{\partial Q} < 0$, $\frac{\partial^2 V_{Tj}}{\partial Q^2} \leq 0$, $\frac{\partial V_{Tj}}{\partial H} < 0$, and $\frac{\partial^2 V_{Tj}}{\partial H^2} \leq 0$. We further assume, as indicated above, that the disutility of search is smaller for a start-up firm: $V_{TF}(Q,H) > V_{TS}(Q,H) \geq 0$. Then for $j = F, S$, the TTO's expected payoff from licensing with contract (R_j, M_j) to firm j is

$$\begin{aligned} P_T(R_j, M_j) &= p(e_j^*, E_j^*; Q, H) U_T(\alpha_T(M_j + R_j), 1) + \\ &\qquad [1 - p(e_j^*, E_j^*; Q, H)] U_T(\alpha_T M_j, 1) - V_{Tj}(Q, H), \end{aligned} \tag{6}$$

where $\alpha_T \in (0,1)$ is its share of license income and $\alpha_T + \alpha_I \leq 1$.[5] If the inventor finds a potential licensee, then the TTO's problem for each $j = F, S$ is to choose a contract to maximize this expected payoff subject to the licensee's participation constraint, or

$$\max_{(R_j, M_j)} P_T(R_j, M_j) \text{ s.t. } P_j(e_j^*, E_j^*) \geq 0. \tag{7}$$

We denote these optimal choices by (R_j^*, M_j^*). If a license contract with positive royalty rate and fixed fee is consummated, then the first order conditions are that the participation constraint holds and

$$\frac{\frac{\partial P_T}{\partial R_j}}{\frac{\partial P_T}{\partial M_j}} = \frac{\frac{\partial P_j}{\partial R_j}}{\frac{\partial P_j}{\partial M_j}}. \tag{8}$$

The condition in (8), of course, denotes a tangency between the expected-payoff indifference curves of the TTO and licensee in (R_j, M_j)-space. An example of this is depicted in Figure 2.

4 Empirical Implications

Our theory provides two types of empirical implications. First, it provides predictions regarding factors that increase the likelihood of commercialization of university inventions via either established firms or start-ups.

Theorem 2 *Licensing to either an established firm or a start-up firm is more likely in the equilibrium of this dynamic licensing and development game for inventors with higher quality and/or lower disutility from development effort, TTOs with greater historical success and/or lower disutility of*

[5] This is generally less than 1 because the university administration also receives a share of revenue.

search for licensees, and inventions with lower costs of development and/or commercialization for potential licensees.

Proof. Obvious. ■

Next, our theory provides predictions regarding factors that increase the likelihood of commercialization of university inventions via start-ups. To derive these implications, we consider those conditions necessary and sufficient for commercialization in start-up firms rather than established firms. Specifically, these are the conditions under which the *unique* equilibrium is that the TTO sells a license to a start-up firm.

Theorem 3 *Licensing to a start-up firm, instead of an established firm, is the equilibrium of this dynamic licensing and development game if and only if either:*
(i) $P_F(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*)) < 0$ *or* $P_T(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*)) < 0$, $P_S(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) \geq 0$, *and* $P_T(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) \geq 0$*; or*
(ii)$P_T(e_j^*(R_j^*, M_j^*), E_j^*(R_j^*, M_j^*)) > 0$ *and* $P_S(e_j^*(R_j^*, M_j^*), E_j^*(R_j^*, M_j^*)) \geq 0$ *for* $j = F, S$, *and* $P_T(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) > P_T(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*))$.

Proof. This follows straightforwardly from the definition of the game and the fact that the TTO and potential licensee payoffs in these statements are evaluated at the equilibrium values of effort that would prevail in the development subgame if a license were executed. ■

We think of the game as unfolding as follows. The TTO, given a disclosure, first considers licensing to an established firm. It determines the solution to (7) for $j = F$, the contract (R_F^*, M_F^*), conditional on equilibrium behavior by the inventor and firm in the development subgame. The TTO next considers shelving the invention, and providing minimal assistance in searching for an investor in a start-up firm. This yields the contract (R_S^*, M_S^*) that solves (7) for $j = S$, conditional on equilibrium behavior by the inventor and firm in the development subgame. Licensing to this start-up is the unique equilibrium, therefore, if either a contract can be sold to a start-up but not an established firm, or if a contract can be sold to either type of firm, but the TTO earns greater expected net utility the optimal start-up contract. Thus, we emphasize that our model is consistent not only with the observation that TTOs may turn to start-ups as a last resort, after the effort to find an established firm has failed, but also with the observation that TTOs may immediately shelve a disclosure and let the inventor pursue a start-up.

If the TTO's disutility of searching were the same for both types of licensee, then a license is sold to a start-up only if has greater (positive) expected profit, gross of license payments, so that the TTO's net utility from licensing to that start-up is greater. Although this may seem unlikely, *a priori*, it is not. Indeed, three types of efficiency can contribute to greater expected profit for a start-up.

First, expected profit depends on the firm's cost of development effort and the cost of attempting to commercialize the invention. The opportunity costs of development and commercialization can be greater for established firms, which typically have alternatives that are more closely related to their current product line, and so more profitable. Conversely, venture capitalists routinely deal with inventions that do not fit well in existing product lines, so they may well have cost advantages from better access to and information about the technological expertise needed to develop and commercialize embryonic inventions. Similarly, start-ups may well have cost advantages due to the inventor's superior knowledge of the technology, which can limit transactional and informational problems.

Second, expected profit also depends upon the post-development probability of success. An inventor often has a closer relationship with a start-up, and may provide greater development effort as a result. A venture capitalist also may provide more effort (resources) than an established firm. Because inventor and firm efforts are strategic complements, greater effort by either induces greater effort by the other, thus further increasing the probability of success and expected profit. The equilibrium of the development subgame, therefore, may involve greater inventor and/or firm effort, and greater expected profit, for start-up.

Third, licensing to a start-up firm can occur, even if expected profit is greater for an established firm, because the TTO's opportunity cost of searching for an established firm as a licensee is greater. This is an assumption of our model, of course, but it is consistent with the stylized facts. TTOs tend to focus their limited time on finding established firms as licensees for their most promising inventions, while essentially ignoring the others, which then typically are commercialized only if the inventors make the lion's share of the effort to find investors to assist them in forming start-ups. This may well be a more efficient approach for such inventions, because the inventors have a better understanding of their embryonic nature, and so should be better able to find potential partners than the TTO.

We summarize the implications of the theory for our empirical analysis in terms of characteristics of the inventor, the invention, the TTO, and financial markets. This approach is arbitrary, but facilitates the discussion.

The primary characteristic of an inventor is his (perceived) quality. Higher quality inventors disclose inventions which, *ceteris paribus*, have higher probabilities of success and lower TTO utility costs of searching, and thus are more likely to be licensed to either established firms or start-ups.

The nature of the invention is also important, in the sense that inventions which result from more applied research are "closer" to commercialization. Such inventions would not only have higher probabilities of success for given levels of effort, but also lower search costs for the TTO, and thus are more likely to be licensed to established firms than start-ups.

TTOs are also an important factor in the commercialization of university inventions. They rely on their experience and expertise in their search for firms to serve as partners in commercializing inventions. Those with more experience and expertise, and with more past success, should be more likely to sell licenses to either established firms or start-ups. TTOs also play a role as intermediaries between inventors and licensees, and as such may serve as guarantors of minimum quality levels (see Hoppe and Ozdenoren 2004 and Macho-Stadler, Perez-Castrillo, and Veugelers 2004). From this perspective, we expect relatively more licenses to established firms and fewer start-ups from more experienced and successful TTOs.

Finally, our theory predicts that financial market conditions, and the availability of capital and credit, should be an important factor in determining whether licensing occurs to start-ups or established firms. These conditions influence the costs of developing and attempting to commercialize the invention, as well as the TTO's cost of searching for a licensee and the probability that the invention will eventually succeed. Venture capitalists play a significant and unique role in start-up activity and innovation.[6] Licensing to start-ups, but not established firms, should be positively related to the general ability of the inventor or TTO to tap into venture capital funding. Similarly, we expect a positive relationship between start-up activity and returns to the S&P 500 because more start-up activity occurs, in general, when business conditions are favorable. However, we expect both the rate of return to venture capital and the interest rate to be negatively related to start-up activity, because higher rates indicate greater opportunity costs of development and commercialization of university start-ups for venture capitalists, who have other, more profitable opportunities.

[6] Kortum and Lerner (2000) find that venture capital fund-raising positively effects patenting rates.

5 Data and Methodology

Data on commercialization of university inventions via start-ups and licenses to established firms were gathered from the AUTM surveys for fiscal years 1993 through 2002. The sample is an unbalanced panel of 110 universities, including 40 private universities, 67 universities with medical schools, and 31 universities in the five states that received the largest venture capital investments. To be precise, our data for "start-ups" are companies formed with the aid of the university technology licensing office in order to commercialize a faculty invention. The AUTM Licensing Survey 2002 states that start-up firms "are companies that were dependent upon licensing the institution's technology for initiation."[7] Our data for "licenses" are those license and option agreements executed with established firms. The universities in our sample generated 3,047 start-ups, 79,579 disclosures and 24,352 licenses during this time period. Table 1 shows the descriptive statistics for the all variables we consider in this sample. The average number of start-ups per university is 3.2 per year, and the average number of licenses is 25.6 per year. Technology transfer offices received 83.2 new invention disclosures per year, and had an average of 3.3 full time employees devoted to licensing activity.

We test our theoretical model using two equations of the form,

$$Y_{it} = \alpha_{it} + \beta_1 X_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + e_{it}. \tag{9}$$

In model 1, the dependent variable is start-ups at university i in year t, and in model 2, the dependent variable is licenses at university i in year t. The independent variables include our proxy measures of inventor quality, X_{1i},TTO characteristics, X_{2it}, invention characteristics, X_{3it} and financial market conditions (including venture capital), X_{4it}. Because the independent variables involve count data, and there are many zeros in the start-up data, our benchmark models 1 and 2 estimate (9) using a negative binomial model.

Because our theory predicts that licensing to start-ups or established firms is positively related to faculty quality, for each university i, we use three measures of inventor quality, X_{1it}: quality of the graduate faculty, $QUAL_i$; quality of the engineering faculty, $ENGQUAL_i$; and quality of the natural sciences faculty, $SCIQUAL_i$. Previous studies have used the data from the 1993 National Research Council's Survey of Ph.D. Granting Institutions (NRC 1995) to construct a quality measure for each university by computing the weighted average of the NRC scores for each department

[7] Association of University Technology Managers Survey FY 2002, page 24.

(where the weights are determined by faculty size). This measure is flawed because it omits faculty without doctoral programs. More importantly, from our perspective, it is also too coarse a measure because it includes faculty in the humanities and social sciences, who are not typically the driving forces behind university licensing and start-up activity. Because most inventions come from faculty in engineering and natural sciences, we also control for quality in these disciplines. For each university, we also construct a weighted average of the NRC quality scores for its engineering departments, and a weighted average of the NRC quality scores for its natural science departments.[8] The NRC rankings for each department in this survey ranged from 0 to 5, where 5 indicates a distinguished department, so higher values of $QUAL_i$ correspond to higher quality of the graduate faculty, higher values of $ENGQUAL_i$ correspond to higher quality of the engineering faculty, and higher values of $SCIQUAL_i$ correspond to higher of the natural sciences faculty. Our theory predicts a positive relationship between any measure of inventor quality and both start-ups and licenses to established firms.

We also use a dummy variable to denote whether the university is private or public ($PRIVATE_i = 1$ if private, 0 otherwise). Private universities may, in general, have higher quality faculty, in which case this dummy variable would be just another proxy for quality. Similarly, private schools may have more flexibility in research options, which would imply more licensing to start-ups and established firms. However, private universities may also have more or better ties to established firms, which would leads us to expect fewer licenses to start-ups than established firms.

Because our theory predicts that licensing to start-ups or established firms depends positively on the TTO's historical success, we also include measures of TTO characteristics as independent variables, X_{2it}. For each university i, in each year t, we use the number of disclosures, DIS_{it}, the age of the technology transfer office, $TTOAGE_{it}$, the size of the technology transfer office, $TTOSIZE_{it}$,and the log of gross royalties, $LNGROSS_{it}$, as proxies for TTO success. TTOs who have elicited more disclosures from their faculty are likely to sell more licenses simply because they have more new inventions in their portfolio. Similarly, TTOs that are older and larger have not only more resources, but also more experience and expertise in evaluating disclosures and in searching for licensees. TTOs with greater gross royalties have more past success, both in selecting disclosures to pursue and in finding licensees for them.

Next, we include two variables as proxies for the characteristics of the

[8] We thank Jerry Thursby for providing his NRC data.

inventions, in terms of their commercial orientation, X_{3it}. We use a dummy variable to measure the presence of a medical school ($MED_i = 1$ if medical school, 0 otherwise). The presence of a medical school suggests the university may produce a higher proportion of inventions that are applied, in the sense that their commercial potential is more obvious. We also include the ratio of industrial research support to federal research support, $INDFED_{it}$, as an invention characteristic. Universities with greater relative industrial funding may also tend to produce a higher proportion of inventions that are applied in nature, and so more apparently suitable for commercialization. Such inventions should be characterized, *ceteris paribus*, by both higher probabilities of success and lower TTO cost of search for established firms as licensees. Thus we expect that the presence of a medical school and high level of relative industrial funding to be positively related to licensing to established firms, but negatively be related to start-up activity.

Finally, because our model predicts that university licensing should be related market conditions and availability of capital and credit, we include several measures of financial market and general business conditions, X_{4it}, as independent variables for the case of start-ups, model 1. First, we use two proxies to measure the TTO's general ability to tap into venture capital funding. These data are obtained from the National Venture Capital Association Yearbook 2004. First, we use the log of venture capital funding in each state for each university i in that state for each fiscal year t from 1993 through 2002, $VCSTATE_{it}$. We also use a dummy variable to denote whether the university is located in one of the six states that received the most venture capital funding[9] ($HIGHVCST_{it} = 1$ if located in a high venture capital state, 0 otherwise). We use state level data because direct data for the universities in our sample is hard to obtain due to legal issues. As noted above, our theory predicts a positive relationship between venture capital spending and licensing to start-ups.

Next, for each year t in the sample, we include the five year rolling averages of the Venture Capital Index, $RLAVEVC_t$ and the Standard and Poors 500 Index $RLAVESP_t$, and the annual percentage change in the Federal Reserve's fed funds rate, $INTEREST_t$.[10] We expect both the average venture capital index and the interest rate to be negatively related to start-up activity, as they proxy the opportunity costs of university start-ups for venture capitalists. However, we expect a positive relationship between start-up ac-

[9] California, New York, Massachusetts, Connecticut, Maryland, and Texas.

[10] Interest rate data is compiled from the St. Louis Federal Reserve Database (FREDII) and the U.S. Department of Labor, Bureau of Labor Statistics.

tivity and returns to the S&P 500, because more start-up activity occurs, in general, when business conditions are favorable.

Finally, we do not include these proxies for venture capital activity and market sentiment in our analysis of licensing to established firms, model 2, because it seems much more likely that these variables play a significant role in licensing decisions by established firms. Our robustness checks in Section 7 confirm this.

6 Empirical Results

The results for our benchmark estimations using the negative binomial model are presented in Table 2. Results for other specifications used as robustness checks are in Tables 3-7.

In general, our results provide strong evidence that inventor quality is positively related to licensing to both start-ups and established firms. The estimated coefficients for our engineering and science quality variables are positive in our benchmark regression estimations both for licensing to start-ups (model 1) and licensing to established firms (model 2). The coefficients for engineering quality are positive and significant, but the coefficients for science quality are not. These findings support our theoretical result that inventions from high-quality faculty are more easily commercialized with either established or start-up firms. These results are similar to the Di Gregoriao and Shane (2003) finding of a positive relationship between start-up formation and faculty quality, as measured by the Gourman Report, for the period 1994-1998. They are also consistent with the Shane and Stuart (2002) finding that intellectual eminence is positively related to start-up activity. Moreover, these results are also consistent with the finding of Jensen, Thursby and Thursby (2003) that higher quality faculty disclose inventions at earlier stages of development, the findings of Lach and Shankerman (2002) that higher quality faculty disclose more inventions and higher value inventions, and the finding of Thursby and Thursby (1998) that faculty are critical in the licensing process. Our results contribute to this literature by evaluating faculty quality and start-up activity in the context of licensing, in general.

We contribute to this literature by using these more precise measures of quality. We also analyzed the data using the original, over-all quality measure from the NRC data that includes all departments. The estimated coefficients for over-all quality are positive in our benchmark regressions both for licensing to start-ups (model 3) and established firms (model 4). However, the coefficients for science quality and engineering quality, when added together, are larger than the coefficient for the over-all quality measure. We checked this result using several estimation techniques as robustness checks and found similar results (see Tables 3-5 and 7). Thus, our more detailed measures for faculty quality have more explanatory power. Interestingly, these results also suggest that it is the quality of engineering faculty that is most important to commercialization of university inventions via either start-ups or established firms.

We find no evidence that our dummy variable for the whether the university is private helped to predict license to start-ups or established firms. For either dependent variable, the estimated coefficient for this indicator variable is negative, but not significant. We believe this may indicate that whether a university is private may simply be a proxy for the quality of potential inventors at that university.

As predicted by our theory, the number of invention disclosures to the TTO is positively and significantly related to licensing to both start-ups and established firms. In our benchmark regressions, and in virtually all of our other model specifications, the estimated coefficients for disclosures are positive and significant. Universities with larger pools of disclosures execute more licenses to both established firms and start-ups Although a larger pool of disclosures may increase the TTO's opportunity cost of searching for a licensee for any one of them, it also increases the number of commercially viable disclosures and thereby generally results in more licensing. This reflects the now well-known fact that university technology transfer relies essentially on the solicitation of disclosures from faculty.

The estimated coefficients for the log of gross licensing royalties are positive and significant for licenses to established firms. The coefficient are positive for start-ups also, but significant only when the single over-all measure of quality is used (Models 3 and 4). These results are reasonably robust, holding for the majority of alternative specifications. Our theory predicts that larger gross licensing royalties, as a measure of greater past TTO success, should increase all licensing. Apparently, those universities that are able to generate many start-ups may not be the same universities that also have large royalty incomes. This is consistent with the stylized fact that the majority of "royalty rich" TTOs obtain their revenue from established firms, and view start-ups as a last resort.

We also find evidence that the age of the TTO positively affects all licensing. The estimated coefficient is positive and significant in the benchmark models. As predicted by our theory, older and more experienced TTOs are more likely to license inventions to both start-ups and established firms.

This result is robust for license to established firm in all alternatives, and for licenses to start-ups in the majority. This is consistent with the results of Lach and Schankerman (2002), who find that disclosures and their average values increase with TTO age, and with the results of Franklin, Wright, and Lockett (2001), who find that older universities are more successful in launching new startups. Feldman Feller, Bercovitz and Burton (2002) similarly find that the greater the amount of experience with technology transfer, the more likely the university will accept equity-based technology transfer mechanisms. Older, experienced TTOs are more effective in commercializing inventions, in general. Thus, although increases in TTO age increase both the probability of success of a given disclosure and the cost of TTO search for an established firm as a partner in our theory, it appears that the former effect outweighs the latter in this data.

It is somewhat surprising that the size of the TTO did not have a significant impact on start-up activity. This coefficient was very small in general, and not significantly different from zero in the benchmark case. Interestingly, this is one result that was not very robust, as TTO size did have a significant impact on licensing to start-ups and established firms in several other specifications. However, these other results were not consistent in that the significant signs often took opposite signs in alternative specifications (see Tables 3-7). This suggests that TTO size need not have a significant or consistent effect on licensing.

The presence of a medical school also did not seem to significantly affect licensing to either start-ups or established firms. The coefficient for medical schools is negative but not significant for licenses to start-ups, but is positive, and still not significant, for licences to established firms. This may indicate that universities with medical schools generate less start-up activity, and support our theory that inventors from medical schools may be more commercially oriented, so it is easier to license their inventions to established firms. It is also consistent with the finding of Jensen, Thursby and Thursby (2003) that universities with higher fractions of their inventions from medical schools have more inventions disclosed at an early stage of development.

The coefficient for the ratio of industrial to federal research support is positive and significant for licenses to both start-ups and established firms. This result was reasonably robust, in that the sign was positive in all specifications, but not always significant. This is perhaps not surprising as Jensen, Thursby and Thursby (2003) find this variable does not help to predict the stage of development at which inventions are disclosed. Following Di Gregoriao and Shane (2003), we also used the ratio of industrial support to total research support in an attempt to capture the applied nature of research, but found no significance with this variable either.

Our results provide evidence that access to venture capital affects start-up activity. The estimated coefficient for the log of venture capital funding in the state where the university is located is positive, but not significant. Similarly, the estimated coefficient for whether the university is located in one of the six states with the most venture capital funding is usually positive, but not significant. Given our theory, we anticipated positive, significant results. Apparently these proxies for the local availability of venture capital are too broadly defined to capture the expected effect.

Nevertheless, we do find evidence that the five year rolling average of returns to venture capital significantly, and negatively, impacts licensing to start-ups. This result is robust to all specifications. When the rate of return to venture capital is high, venture capitalists have many opportunities that are more lucrative than start-ups based on university inventions, and they obvious pursue these. Alternatively stated, given the embryonic nature of university inventions, the evidence suggests that venture capitalists turn to university start-ups as a last resort.

Finally, we find evidence that interest rate changes significantly impact start-up activity. The estimated coefficient for interest rate percentage change is negative and significantly different from zero in each regression specification. As interest rates rise, available capital for start-up formation decreases. We also find evidence that the rate of growth in the S&P 500 index is positively and significantly related to start-up activity. Increases in the S&P 500 reflect improvements in overall business sentiment, which leads to more university start-up activity. These result lend support to our view that indicators of economics activity and market sentiment positively affect start-up activity.

7 Robustness Checks

We checked our results using several tests for robustness. First, given concerns about possible endogeneity of some of the TTO characteristics, we also estimated our benchmark model using both lagged disclosures and lagged cumulative disclosures, and the lagged log of gross royalties. Our results remained the same in these specifications. Also, to check whether financial market variables mattered only for licenses to start-ups, we also estimated our benchmark model for licenses to established firms including financial market variables, and none of these coefficients was significant.

Because we began the analysis, as usual, by examining a simple OLS specification, we also decided to check whether contemporaneous cross-equation error correlation existed. It is possible that our benchmark model 1 and model 2 are related through the correlation in the error terms. In Table 7, we show results from the estimation of three seeming unrelated regressions. We found no correlation in error terms. Estimating these two equations separately seems to lend greater explanatory power.

We also empirically tested our theoretical model using random effects models to account for any unobserved inter-university differences or clustering effects that may exist. This design allows for additional sources of variation in the model to examine variance of error terms across universities for contemporaneous correlation between cross-sections. We estimated a model using a random effects specification that allowed for in-state dependence between universities but assumed no dependence between universities across states. These results in Table 5 were largely similar to those in Table 2, our benchmark model and the standard errors were very similar. It does not appear that university inter-dependence or cross-sectional effects significantly impact our findings. Thus, we found no need to conduct cross-section weighted estimations.

Finally, we also tested our theory using fixed-effects models. We check for any unmodeled heterogeneity and assume that individual specific time invariant effects may exist (see Table 6). We added a time trend to further examine the positive relationship between our proxies for cost, venture capital spending and start-up firm activity and licensing to established firms. This model excludes our quality measures and indicator variables for whether the university has a medical school or is public or private. These results are also still very similar to those in Table 2, our benchmark model.

8 Conclusion

We have developed and empirically tested a theoretical model to explain why commercialization of university research occurs in start-up firms rather than established firms. Several empirical implications follow immediately from the theory. Essentially, we are more likely to observe commercialization of university inventions by start-up firms in situations in which start-ups are more likely to have a cost advantage in the development or commercialization of the invention, or in which the opportunity cost of TTOs in searching for an established firm as a partner is higher.

We tested the implications of the model in terms of characteristics of the inventor, the invention, and the TTO, and financial market conditions. We estimated negative binomial, Poisson, ordinary least squares, fixed effects and random effects models using the annual number of licenses to start-ups and licenses to established firms per university. Our results provide evidence that inventor quality, especially in engineering departments, has a positive impact on licensing in general. We also find that measures of TTO success, such as disclosures, the age of the TTO, and gross royalties, have a positive impact on licensing in general. Financial market variables also matter, as we find that both the rate of return to venture capital and the interest rate have negative and significant effects on the number of university start-ups, but the S&P 500 has a positive and significant effect on start-ups. Our analysis therefore indicates that university inventions are so embryonic that, if an established firm is unwilling to take a license, then it is very difficult to fund a start-up because even venture capitalists come to university inventions only as a last resort.

9 References

Association of University Technology Managers, *1995, 1996, 1997, 1998, 2000,* and *2001, AUTM Licensing Surveys.*

Bercovitz, J., M. Feldman, I. Feller, and R. Burton, 2001, Organizational Structure as a Determinant of Academic Patent and Licensing Behavior: An Exploratory Study of Duke, Johns Hopkins, and Pennsylvania State Universities, *Journal of Technology Transfer* 26, 21-35.

Di Gregoriao, D. and S. Shane, 2003, "Why Do Some Universities Generate More Start-ups Than Others?," *Research Policy* 32, 209-227.

Feldman, M., I. Feller, J. Bercovitz, and R. Burton, 2002, "Equity and Technology Transfer Strategies of American Research Universities," *Management Science* 48 , 105-121.

Hellmann, Thomas, 2005, "The Role of Patents for Bridging the Science to Market Gap," mimeo, University of British Columbia.

Henderson, Rebecca, Adam Jaffe and Trajtenberg, 1998, "Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965-1988," *Review of Economics and Statistics*, 119-127.

Hoppe, Heidrun C., and Emre Ozdenoren, 2004, Intermediation in Innovation: The role of Technology Transfer Offices," mimeo, Universitat Hamburg.

Jensen, R., and M. Thursby, 2001, Proofs and Prototypes for Sale: The Licensing of University Inventions," *American Economic Review* 91, 240-

259.

Jensen, R., J. Thursby, and M. Thursby, 2003, "The Disclosure and Licensing of University Inventions: 'The Best We Can Do With the S**t We Get To Work With," *International Journal of Industrial Organization 21*, 1271-1300.

Kortum, S. and J. Lerner, 2000, "Assessing the Contribution of Venture Capital to Innovation," *Rand Journal of Economics* 31, 674-692.

Lach, S. and M. Shankerman, 2002, "Incentives and Inventive Activity in Universities," mimeo, Hebrew University and London School of Economics.

Lerner, J. 1999, "The Government as a Venture Capitalist: The Long run impact of the SBIR Program J. Bus. 72 285-318.

Levin, S. and P. Stephan, 1991, "Research Productivity over the Life Cycle: Evidence for American Scientists," *American Economic Review 81, 114-132.*

Lewis, K.S., L.M. Jones, M.S. Anderson, D. Blumenthal, and E.G. Campbell, 2001, "Entrepreneurship, Secrecy, and Productivity: A Comparison of Clinical and Nonclinical Faculty," *Journal of Technology Transfer* 26, 233-245.

Lowe, R. and A. Ziedonis, 2004, "Start-ups, Established Firms, and the Commercialization of University Inventions," mimeo.

Macho-Stadler, I., D. Perez-Castrillo, and R. Veugelers, 2004, "Licensing of University Innovations: The Role of a Technology Transfer Office," mimeo, Universitat Autonoma de Barcelona and Katholieke Universiteit Leuven.

Mowery, D., R. Nelson, B. Sampat and A. Ziedonis, 2001, "The Growth of Patenting and Licensing by U.S. Universities: An Assessment of the Effects of the Bayh-Dole Act of 1980," *Research Policy* 30, 99-119.

Mowery, D. and B. Sampat, 2001, "University Patents and Patent Policy Debates in the USA, 1925-1980," *Industrial and Corporate Change* 10, 781-814.

Nelson, R. "What is Private and What is Public about Technology?" 1989, *Science, Technology and Human Values* 14(3), 229-241.

Owen-Smith, J. and W.W. Powell, 2001, To Patent or Not: Faculty Decisions and Institutional Success at Technology Transfer, *Journal of Technology Transfer* 26, 99-114.

Shane, S., 2000, "Prior Knowledge and the Discovery of Entrepreneurial Opportunities," *Organization Science* 11, 448-469.

Shane, S., 2001, "Technological Opportunities and New Firm Creation," *Management Science* 47, 204-220.

Shane, S., 2002, “Selling University Technology,” *Management Science* 48, 122-137.

Shane S. and D. Somaya, 2004, “The Effects of Patent Litigation on University Licensing Efforts,” mimeo.

Shane, S. and T. Stuart, 2002, “Organizational Endowments and the Performance of University Start-ups,” *Management Science* 48.

Siegel, D., D. Waldman, and A. Link, 1999, Assessing the Impact of Organizational Practices on the Productivity of University Technology Transfer Offices: An Exploratory Study,” NBER Working Paper 7256.

Stephan, P., 1996, “The Economics of Science,” *Journal of Economic Literature* 34(3), 1199-1235.

Thursby, J., R. Jensen, and M.C. Thursby, 2001, Objectives, Characteristics and Outcomes of University Licensing: A Survey of Major U.S. Universities, *Journal of Technology Transfer* 26, 59-72.

Thursby, J. and S. Kemp, 2002, Growth and Productive Efficiency of University Intellectual Property Licensing,” *Research Policy* 31, 109-124.

Thursby, J., and M.C. Thursby, 2002, “Who is Selling the Ivory Tower? Sources of Growth in University Licensing,” *Management Science 48(1), 90-104.*

Thursby, J., and M.C. Thursby, (1998) “Are Faculty Critical? Their Role in University-Industry Licensing, *Contemporary Economic Policy 22*, 162-178.

Thursby, M.C., J. Thursby, and E. Dechaneaux, 2004, “Shirking, Shelving, and Risk-sharing: The Role of University License Contracts,” mimeo.

Thursby, J., and M.C. Thursby, 2004, “Patterns of Research and Licensing Activity of Science and Engineering Faculty,” in Ehrenberg, R. and P. Stephan, eds., *Science and the University,* Madison: University of Wisconsin Press (forthcoming).

10 Appendix: Proof of Theorem 1.

Existence of at least one Nash equilibrium follows immediately from the fact that the payoffs are continuous and defined on compact strategy spaces. As noted in the text, for each $j = F, S$, the continuity and strict concavity of P_I guarantees that it is maximized at some $e_j \in [0, \hat{e}]$, and so there exists an inventor best-reply function $b_I(E_j)$. If $\frac{\partial P_I(0,\hat{E}_j)}{\partial e_j} \leq 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_I(0,E_j)}{\partial e_j} < 0$ for all $E_j \in [0, \hat{E}_j)$, so P_I has its maximum at $e_j = 0$, and $b_I(E_j) = 0$ for all $E_j \in [0, \hat{E}_j]$. Similarly, the continuity and strict concavity of each P_j guarantees that it is maximized at some $E_j \in [0, \hat{E}_j]$, and so there exists a firm j best-reply function $b_j(e_j)$. If $\frac{\partial P_j(\hat{e},0)}{\partial e_j} \leq 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_j(e_j,0)}{\partial E_j} < 0$ for all $e_j \in [0, \hat{e})$, so P_j has its maximum at $E_j = 0$, and $b_j(e_j) = 0$ for all $e_j \in [0, \hat{e}]$. This proves statement (i). Conversely, if $\frac{\partial P_j(0,0)}{\partial E_j} > 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_j(e_j,0)}{\partial E_j} > 0$, and so $b_j(e_j) > 0$, for all $e_j > 0$; and if $\frac{\partial P_I(0,0)}{\partial e_j} > 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_I(0,E_j)}{\partial e_j} > 0$, and so $b_I(e_j) > 0$, for all $E_j > 0$. This proves statement (ii). Statement (iii) then follows from the definition of uniqueness and locally stability. Q.E.D.

Table 1. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Start-up Companies Formed	951	3.203996	5.624048	0	64
Licenses and Options Executed	951	25.60673	35.73951	0	313
<u>Inventor Characteristics</u>					
NRC overall Quality Engineering Ranking weighted by department	830	2.867632	0.817586	1.24	4.631456
NRC overall Quality Sciences Ranking weighted by department	1080	2.974425	0.832695	0.717059	4.746132
NRC overall Quality Ranking weighted by department	1100	2.923386	0.798214	1.203704	4.697401
University is private (yes = 1)	1100	0.355455	0.478869	0	1
<u>TTO Characteristics</u>					
Licensing FTE's in Technology Transfer Offices	951	3.259474	5.026659	0	62
TTO Age - Program Year Technology Transfer Office Began	971	14.19773	12.27503	0	77
Invention Disclosures Received	956	83.24163	100.1542	0	973
Log of Gross License Income Received	950	13.88279	1.977126	6.60665	19.40562
<u>Invention Characteristics</u>					
University has Medical School (yes = 1)	1100	0.592727	0.49155	0	1
Industrial/Federal Research Expenditure	951	0.176505	0.182519	0	1.610801
<u>Financial/Market Conditions</u>					
Interest Rate Level	1100	2.073583	1.246248	0.0225	3.753333
Log of Venture Capital Expenditure per State	1100	18.87763	2.964445	0	24.4911
University is located in a High Venture Capital Expenditure State (yes = 1)	1100	0.273636	0.446027	0	1
Returns to Venture Capital	1100	27.78	12.47522	11.2	48.6
Returns to the S & P 500 index	1100	13.06	7.591099	-1.9	26.2

Table 2. Negative Binomial Regressions Predicting the Effect of Inventor Quality, TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

Dependent Variable	Model 1 Start-ups	Model 2 Licenses	Model 3 Start-ups	Model 4 Licenses
Inventor Characteristics				
ENGQUAL	0.447	0.464		
	(0.141)**	(0.130)**		
SCIQUAL	0.063	0.083		
	(0.155)	(0.136)		
QUAL			0.456	0.471
			(0.091)**	(0.073)**
PRIVATE	-0.11	-0.182	-0.155	-0.11
	(0.138)	(0.117)	(0.124)	(0.106)
TTO Characteristics				
TTOSIZE	0.003	-0.003	0.001	-0.004
	(0.008)	(0.004)	(0.008)	(0.004)
TTOAGE	0.009	0.014	0.009	0.012
	(0.004)*	(0.004)**	(0.004)*	(0.004)**
DIS	0.002	0.002	0.002	0.002
	(0.001)**	(0.000)**	(0.001)**	(0.000)**
LNGROSS	0.058	0.122	0.076	0.136
	(0.035)	(0.022)**	(0.030)*	(0.018)**
Invention Characteristics				
MED	0.171	0.135	-0.12	-0.045
	(0.121)	(0.11)	(0.107)	(0.097)
INDFED	0.731	0.485	0.463	0.37
	(0.257)**	(0.163)**	(0.247)	(0.150)*
Financial/Market Conditions				
INTEREST	-0.472		-0.488	
	(0.034)**		(0.031)**	
LNVCSTAT	0.028		0.043	
	(0.02)		(0.020)*	
HIGHVCST	0.13		-0.06	
	(0.152)		(0.134)	
RLAVEVC	-0.011		-0.016	
	(0.003)**		(0.003)**	
RLAVESP	0.061		0.064	
	(0.006)**		(0.006)**	
Constant	-1.927	-1.918	-2.076	-1.722
	(0.544)**	(0.359)**	(0.501)**	(0.291)**
Observations	655	659	845	847
Log likelihood	-1344.2918	-2355.8865	-1675.345[illegible]	-2942.4997

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 3. Poisson Regressions Predicting the Effect of Inventor Quality, TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

	Model 1	Model 2	Model 3	Model 4
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics				
ENGQUAL	0.527	0.341		
	(0.151)**	(0.196)		
SCIQUAL	0.066	0.566		
	(0.161)	(0.208)**		
QUAL			0.573	0.802
			(0.098)**	(0.087)**
PRIVATE	-0.091	-0.452	-0.048	-0.413
	(0.138)	(0.158)**	(0.134)	(0.132)**
TTO Characteristics				
TTOSIZE	0.001	-0.009	0.005	-0.01
	(0.007)	(0.002)**	(0.007)	(0.002)**
TTOAGE	0.008	0.062	0.01	0.054
	(0.005)	(0.004)**	(0.005)*	(0.003)**
DIS	0.002	0.001	0.002	0.001
	(0.000)**	(0.000)**	(0.000)**	(0.000)**
LNGROSS	0.046	0.052	0.072	0.088
	(0.035)	(0.013)**	(0.027)**	(0.011)**
Invention Characteristics				
MED	0.192	0.091	-0.107	-0.04
	(0.124)	(0.161)	(0.117)	(0.128)
INDFED	0.823	0.583	0.526	0.466
	(0.197)**	(0.100)**	(0.191)**	(0.093)**
Financial/Market Conditions				
INTEREST	-0.53		-0.538	
	(0.023)**		(0.021)**	
LNVCSTAT	0.031		0.04	
	(0.015)*		(0.014)**	
HIGHVCST	0.042		-0.075	
	(0.153)		(0.146)	
RLAVEVC	-0.014		-0.017	
	(0.003)**		(0.003)**	
RLAVESP	0.069		0.068	
	(0.004)**		(0.004)**	
Constant	-1.995	-1.417	-2.25	-1.45
	(0.462)**	(0.371)**	(0.429)**	(0.284)**
Observations	655	659	845	847
Log likelihood	-1431.0948	-2821.9427	-1809.517	-3470.515

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 4 OLS Regressions Predicting the Effect of Inventor Quality, TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

	Model 1	Model 2	Model 3	Model 4
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics				
ENGQUAL	1.018	8.673		
	(0.477)*	(2.511)**		
SCIQUAL	0.088	1.116		
	(0.497)	(2.614)		
QUAL			0.819	6.038
			(0.292)**	(1.377)**
PRIVATE	0.111	-2.831	0.126	-3.46
	(0.464)	(2.245)	(0.392)	(1.783)
TTO Characteristics				
TTOSIZE	-0.054	2.454	0.042	2.031
	(0.058)	(0.307)**	(0.014)**	(0.261)**
TTOAGE	0.044	0.767	-0.036	0.718
	(0.014)**	(0.076)**	(0.054)	(0.067)**
DIS	0.025	0.08	0.024	0.114
	(0.003)**	(0.018)**	(0.003)**	(0.015)**
LNGROSS	-0.03	1.474	0.042	1.629
	(0.136)	(0.708)*	(0.108)	(0.518)**
Invention Characteristics				
MED	-0.314	0.93	-0.813	-2.782
	(0.405)	(2.096)	(0.338)*	(1.637)
INDFED	2.191	3.899	1.353	0.171
	(1.064)*	(5.587)	(0.945)	(4.606)
Financial/Market Conditions				
INTEREST	-2.465		-2.351	
	(0.218)**		(0.195)**	
LNVCSTAT	0.011		0.049	
	(0.074)		(0.062)	
HIGHVCST	0.26		0.262	
	(0.539)		(0.442)	
RLAVEVC	-0.085		-0.087	
	(0.018)**		(0.016)**	
RLAVESP	0.343		0.314	
	(0.039)**		(0.035)**	
Constant	0.478	-48.271	0.252	-38.293
	(1.898)	(8.862)**	(1.59)	(6.674)**
Observations	655	659	845	847
R-squared	0.46	0.67	0.4191	0.67

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 5. Random Effects Regressions Predicting the Effect of Inventor Quality, TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

	Model 1	Model 2	Model 3	Model 4
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics				
ENGQUAL	1.149	5.095		
	(0.646)	(5.088)		
SCIQUAL	0.06	2.67		
	(0.681)	(5.358)		
QUAL			0.859	5.976
			(0.348)*	(2.429)*
PRIVATE	0.215	-4.287	0.174	-4.374
	(0.637)	(4.46)	(0.48)	(3.568)
TTO Characteristics				
TTOSIZE	0.015	0.334	0.013	0.224
	(0.068)	(0.34)	(0.06)	(0.29)
TTOAGE	0.047	0.763	0.044	0.731
	(0.020)*	(0.144)**	(0.017)**	(0.124)**
DIS	0.021	0.183	0.022	0.189
	(0.004)**	(0.020)**	(0.003)**	(0.017)**
LNGROSS	-0.049	1.016	0.028	1.011
	(0.166)	(0.855)	(0.123)	(0.624)
Invention Characteristics				
MED	-0.262	1.553	-0.802	-0.726
	(0.552)	(4.214)	(0.411)	(3.276)
INDFED	1.913	8.571	1.14	6.721
	(1.171)	(5.387)	(1.018)	(4.496)
Financial/Market Conditions				
INTEREST	-2.472		-2.36	
	(0.205)**		(0.187)**	
LNVCSTAT	0.031		0.053	
	(0.078)		(0.066)	
HIGHVCST	0.087		0.127	
	(0.715)		(0.531)	
RLAVEVC	-0.086		-0.088	
	(0.017)**		(0.015)**	
RLAVESP	0.348		0.318	
	(0.037)**		(0.034)**	
Constant	0.183	-38.883	0.316	-31.691
	(2.268)	(12.558)**	(1.769)	(9.327)**
sigma_u	1.506104	15.64351	1.1167678	14.251912
sigma_e	4.036787	16.05907	4.0828955	14.671985
rho	0.122191	0.486894	0.0696074	0.4854797
R-sq: within	0.2218	0.2468	0.1969	0.247
R-sq: between	0.723	0.7354	0.7052	0.7411
R-sq: overall	0.4536	0.641	0.4184	0.6467
Observations	655	659	845	847

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Table 6. Fixed Effects Regressions Predicting the Effect of TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

Dependent Variable	Model 1. Start-ups	Model 2 Licenses
TTO Characteristics		
TTOSIZE	0.239	-0.638
	(0.095)*	(0.335)
TTOAGE	-0.124	1.303
	(0.123)	(0.251)**
DIS	0.015	0.191
	(0.005)**	(0.019)**
LNGROSS	0.06	0.264
	(0.215)	(0.215)
Invention Characteristics		
INDFED	0.556	8.888
	(1.329)	(4.736)
Financial/Market Conditions		
INTEREST	-2.325	
	(0.189)**	
LNVCSTAT	0.06	
	(0.081)	
RLAVEVC	-0.06	
	(0.029)*	
RLAVESP	0.297	
	(0.042)**	
LNCAINE		
Constant	3.685	-11.564
	(3.014)	(9.41)
sigma_u	3.194713	19.47604
sigma_e	4.089992	14.69187
rho	0.37893	0.637327
R-sq: within	0.2058	0.253
Observations	845	847

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Table 7. Seemingly Unrelated Regressions Predicting the Effect of Inventor Quality, TTO Experience and Financial Market Conditions on Start-up Activity and Licensing to Established Firms

	Model 1		Model 2		Model 3	
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics						
ENGQUAL	1.018	9.507	0.985			8.627
	(0.472)*	(2.506)**	(0.471)*			(2.498)**
SCIQUAL	0.088	1.036	0.107			0.898
	(0.491)	(2.609)	(0.491)			(2.605)
QUAL				9.145	0.987	
				(1.818)**	(0.340)**	
PRIVATE	0.111	-1.157	0.113	-0.964	0.112	-2.629
	(0.458)	(2.436)	(0.458)	(2.421)	(0.453)	(2.234)
TTO Characteristics						
TTOSIZE	-0.054	2.542	-0.055	2.441	-0.064	2.454
	(0.058)	(0.306)**	(0.058)	(0.307)**	(0.057)	(0.304)**
TTOAGE	0.044	0.762	0.044	0.738	0.042	0.771
	(0.014)**	(0.076)**	(0.014)**	(0.076)**	(0.014)**	(0.075)**
DIS	0.025	0.081	0.025	0.093	0.026	0.08
	(0.003)**	(0.018)**	(0.003)**	(0.018)**	(0.003)**	(0.018)**
LNGROSS	-0.03	1.174	-0.028	1.439	-0.004	1.458
	(0.135)	(0.717)	(0.135)	(0.702)*	(0.131)	(0.707)*
Invention Characteristics						
MED	-0.314	1.085	-0.323	-2.384	-0.685	0.755
	(0.4)	(2.127)	(0.4)	(2.018)	(0.378)	(2.085)
INDFED	2.191	3.247	2.182	0.268	1.901	3.836
	(1.052)*	(5.588)	(1.052)*	(5.526)	(1.035)	(5.539)
Financial/Market Conditions						
INTEREST	-2.465	1.296	-2.466	1.222	-2.48	
	(0.216)**	(1.146)	(0.216)**	(1.154)	(0.216)**	
LNVCSTAT	0.011	-0.406	0.011	-0.241	0.03	
	(0.073)	(0.39)	(0.073)	(0.39)	(0.073)	
HIGHVCST	0.26	-2.922	0.26	-3.617	0.199	
	(0.532)	(2.828)	(0.532)	(2.857)	(0.535)	
RLAVEVC	-0.085	0.149	-0.085	0.126	-0.088	
	(0.017)**	(0.093)	(0.017)**	(0.093)	(0.017)**	
RLAVESP	0.343	0.04		0.044	0.343	
	(0.039)**	(0.206)	(0.039)**	(0.207)	(0.039)**	
Constant	0.478	-46.355		-46.912	0.387	-47.382
	(1.876)	(9.966)**	(1.876)	(10.087)**	(1.888)	(8.861)**
Observations	655	655	655	655	655	655
R-squared	0.4551	0.6742	0.4551	0.6693		

Standard errors in parentheses
* significant at 5%; ** significant at 1%

	Model 1	Model 2	Model 3
Breusch-Pagan test of independence: chi2(1) =	0.682, Pr = 0.4091	0.594, Pr = 0.4411	0.648, Pr = 0.4209

Figure 1

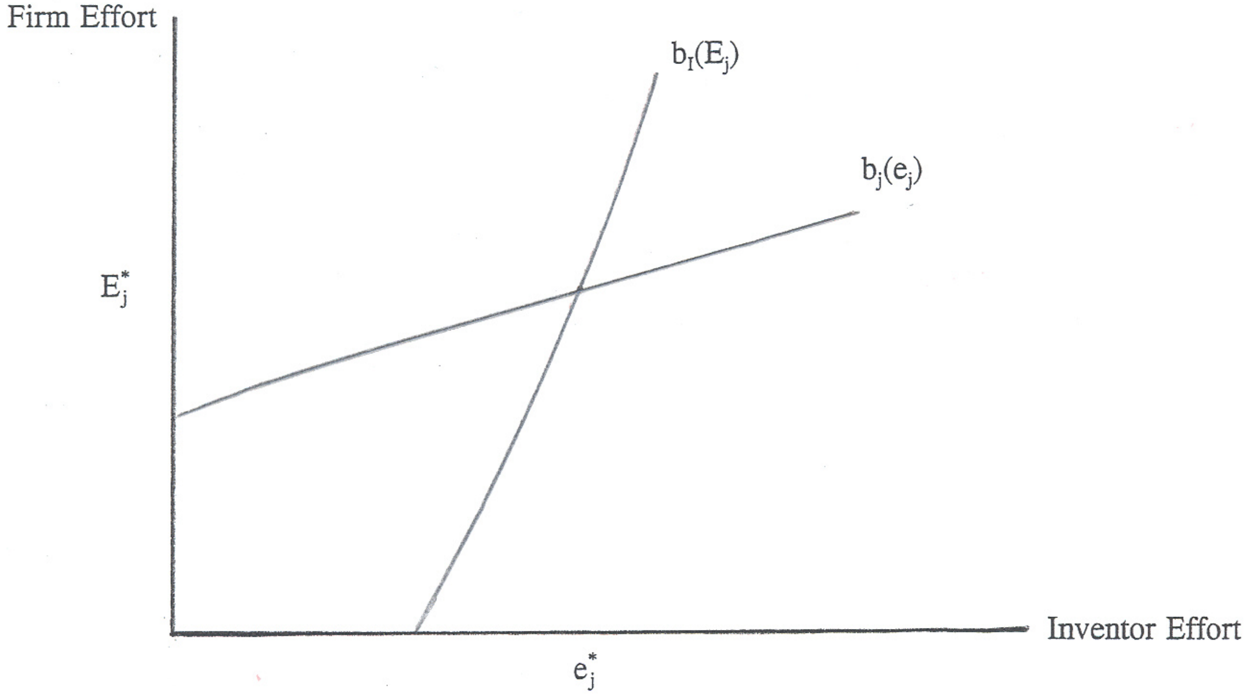

Figure 2